"A Contribution to the Question of Blaze Currents." By Dr Arnold Durig, of Vienna. Communicated by Augustus D. Waller, M.D., F.R.S. Received November 20,—Read December 4, 1902.

(From the Oxford Physiological Laboratory.)

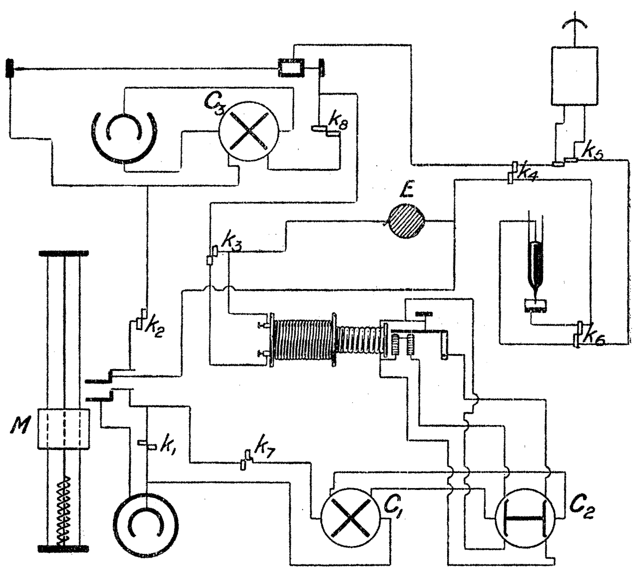
(Translated from the German by Miss F. Buchanan, D.Sc.)

The numerous experiments of Waller on this subject have raised the question as to whether the phenomena of the so-called "blaze currents" are to be regarded as a proof of the persistence of life. It is the purpose of the present communication to give the results of a few experiments which bear upon the subject. These relate principally to the response of the eyeball, but also to that of a few other organs of the frog, to single induction shocks. As they are not yet definitively concluded, I propose here to give only a short description of them, and not to refer to their theoretical significance beyond pointing out that the results obtained must be taken into account before deciding whether or not the currents in question furnish an unmistakable sign of vitality in tissues.

As regards method, the great importance of determining the exact moment after excitation, when the first trace of a current appears, must be insisted upon. It is essential to know whether or not it is after a latent period, and to know its direction, in order to ascertain whether, in addition to the reaction of living tissue, polarisation effects are also being observed. The capillary electrometer has advantages over the more inert galvanometer for this purpose, since the velocity with which the meniscus moves when it first begins to be acted upon by a difference of potential, as determined from the photographic record of the excursion, would enable one to recognise the existence of a polarisation current when it is in the same direction as the "blaze current." Such records have, however, still to be made. The diagram shows the arrangement of the apparatus employed.

By the commutator C_1 in the primary circuit, the direction of the exciting current could be reversed. By means of C_2 the current could be sent to the primary coil either direct or after passing through a Neef's hammer. The key, K_1, served to determine whether the current should be made or broken, the spring-myograph, M, opening accordingly, either the primary circuit itself, or a bridge short-circuiting it. It was thus possible to excite the preparation in immediate succession by ascending or descending, make or break, induction shocks, and to excite it after faradisation by a single shock in either direction. Another contact, for short-circuiting the galvanoscope, was so arranged as to be broken by the myograph immediately after

it had broken, or made, the primary circuit. The distance between this contact and one in the primary circuit was of course so chosen that the induction current itself should produce no effect in the measuring instrument. As the sudden letting in of a resting current would have caused great disturbances in the measuring instrument when the short-circuit was broken, it was necessary to compensate this very carefully beforehand. By means of the key K_2 the compensation could be tested immediately before letting go the myograph. The myograph-stand itself was placed in an adjoining room in order that the movement of its steel rod might not affect the galvanometer. It could however be set in motion from the table on



which the rest of the apparatus was placed. The secondary coil could be short-circuited by the key K_3; the measuring instrument by the key K_4, the keys K_5 and K_6 allowing of the introduction of either galvanometer or capillary electrometer to serve as such, in order that the results obtained with the one instrument might be quickly checked by the other. Although the arrangement was well adapted for concordant observations, it was defective, not only in the absence of the apparatus for recording the movements of the electrometer, but also in another more important respect. The necessity of distinguishing what is due to polarisation in the study of "blaze currents" has already been pointed out. With this in view observations ought to be made in such a way as to eliminate the effects of polarisation as much as possible, as would be accomplished by using, to produce a single exci-

tation, two almost instantaneous induction shocks, as nearly as possible equal in strength, but opposite in direction, according to the method first introduced by Bernstein and by Hermann in rheotome experiments. The use of an instantaneous make and break contact for the myograph and the introduction of a coil, suitably wound so as to avoid induction, or of an incandescent lamp, into the primary circuit, would have been a simple means of attaining this end.

To fully acquaint the reader with what is new in the following results, and with what is merely confirmatory of the observations of others, that is to say of those of Waller, would make the present communication too lengthy. I will, therefore, take it for granted that Waller's researches, which form the starting-point of the subject, are known.

For the experiments on the eye the organ was kept either in daylight or in the dark. The whole eyeball, or the special part of it that was being investigated, lay in a slight depression of a kaolin (unpolarisable) electrode, and was connected by a thread of wick moistened in physiological salt solution to the second electrode. The experiments were always made on the freshly-removed eye, and so relate to Waller's first stage only. A few observations were made on curarised frogs, the optic nerve being exposed by the removal of part of the skull, and looped round by a piece of wick to lead it off to the galvanometer. Since a certain amount of bleeding ensued when the optic nerve was cut, it was especially ascertained at the end of each such experiment that the eye-circulation was maintained. In all the experiments attached pieces of muscle and connective tissue were carefully removed from the eyeball.

The results obtained by the two measuring instruments, the galvanometer and the capillary electrometer, are fully in accordance with one another; the responses to single induction shocks appear, however, distinctly smaller in the galvanometer than in the capillary electrometer. In the latter instrument the effect exceeds the current of rest in size, being more than twice and sometimes several times as great when cornea and optic nerve are led off. Since the response to light stimulation is hardly perceptible in the capillary electrometer, one sees at once how considerable are the differences of potential of which the "blaze currents" are the manifestation (Waller).

Experiments on the whole Eyeball when the middle of the Cornea and the cut end of the Optic Nerve are led off from.

The cornea is always positive to the optic nerve. If the electrode is moved away from the middle of the cornea nearer to the equator of the eyeball, the current of rest becomes less, and if moved beyond the equator to the posterior part of the eyeball it may be reversed.

It is possible to so place the electrode that there shall be no resting current, and this is especially the case in the curarised animal in which the eye-circulation is maintained (Hermann, Holmgren). When the experiment lasted some time the current of rest became reversed, even when the middle of the cornea was led off from. The *response to light* is always in the positive direction, *i.e.*, in the same direction as the current of rest. This positive variation is preceded by a negative initial jerk (Vorschlag). When the light is extinguished a further positive change occurs which subsequently diminishes, at first quickly and then more slowly. Within certain limits the extent of the excursion increases with the duration and strength of the illumination. No negative initial jerk could be observed in the eye of the living frog in response to light; the increase which occurred when the illumination ceased was, however, greater and lasted for a longer time than in the excised eyeball. The return of the needle took place no more quickly than in the excised eye, notwithstanding the maintenance of the circulation and the consequent greater activity of assimilation processes.

Excitation of the eye in the dark by light after previous excitation by electric currents usually resulted in an augmentation of the excursion, the excursions actually observed being greater than the sum of the after-effect produced in response to the induction current and the excursion which is the normal response to illumination alone. A still more striking augmentation of the effect occurred after previous faradisation (Waller). The fact that the augmentation occasionally eluded observation may be due to the circumstance that the sensitiveness of the galvanometer had often to be reduced by a tenth on account of the largeness of the excursion due to the combined effect of "blaze-currents" and light currents.

Electrical effects in response to light are given not only by the *pars optica retinæ*, but can be obtained also from the anterior part of the eyeball alone, the excursions, which could only be observed by galvanometer, being, however, very small. The possibility that the heat of the small incandescent lamp which was used for giving the light-stimulus may have been responsible for the effect must be borne in mind, and alterations which may have been produced in the muscles of the iris must also be taken into account. I am at present engaged in making the further experiments that are required with regard to this matter.

The results obtained with the eyeball in response to *excitation by electrical currents* are not in any way affected by the absence or presence of light. The currents which occur in the uninjured eye in response to such stimulation are, therefore, independent of the effects produced by light, and are to be sharply distinguished from them. (Waller.) This is confirmed by the following new observation:—

When the one leading-off electrode is moved away from the cornea towards the equator of the eyeball, not only is the difference of potential between the two poles diminished, but also the effect produced by an induction shock, which was before considerable, has now almost vanished. Instead of an excursion extending over 600 divisions it now extends over only 20 or 30, and its direction occasionally varies with that of the induction current. When the electrode is replaced on the cornea the original large deviation is again produced in response to stimulation.

When the breaking of the second contact by the myograph lets the preparation into the capillary electrometer, two different main types of response may be distinguished by the form of the observed effect. The curve is either distinctly diphasic, the first phase being negative, *i.e.*, in the opposite direction to the resting current, and the second, which is always considerably stronger, being positive and lasting for a much longer time; or a purely monophasic variation is obtained which is always positive. The negative part of the diphasic variation was so soon over that when, by means of a turn-over key, the preparation was connected with the galvanometer by hand instead of by the myograph, the most that could be observed as the last trace of the first phase was, on account of the relatively great inertia of the galvanometer, an excursion of a few divisions only, by reason of the relatively great inertia of the galvanometer. The phenomenon of the diphasic effect occurs when the induction currents—especially break-shocks—are in the same direction as the "blaze current" is expected to be in, which suggests that one is here dealing with pure polarisation phenomena which do not show themselves when the exciting current is in the opposite direction, as the two effects are then in the same direction. Experiments with this in view are needed to make the matter clear. No explanation has, so far as I am aware, been offered before of the occasional absence of the first phase, which, if it is merely a polarisation effect, must be a physical change independent of any processes in living tissue.

Faradisation produces a distinct augmentation of the resting current, which, however, varies greatly in size and duration in different preparations. Break and make induction shocks in either direction are effectual after faradisation, and produce positive variations which appear as an increase of the augmentation. It is only after very strong faradisation that single induction shocks are ineffectual; in this case the initial augmentation of the pre-existing current (due to the faradisation) soon begins to disappear, the diminution continuing until a resting current in the opposite direction is produced.

The fact that the effects of excitation are so small when the equator

and the posterior part of the eyeball are led off from, is sufficient to suggest that the real seat of origin of the "blaze currents" is to be sought for in the anterior part of the eye. Waller, who at first* regarded the "blaze currents" as having their origin in the retina, has in a subsequent† publication, stated that tissues, other than retinal, take part in their production.

Observations on Separate Parts of the Eyeball.

If the *posterior part of the eye* alone is placed on the electrodes and stimulated, the response is the same as in the whole eye when the equator is led off from, *i.e.*, only a very slight variation occurs. If the *anterior part of the eye* is investigated by itself, the effects produced are the same as when cornea and optic nerve are led off from. It was, therefore, obvious that cornea, lens, and ciliary body must next be investigated separately. One would especially expect to get electromotive effects with the *ciliary ring* on account of the attached iris and its muscles. Experiment showed that break and make induction shocks in either direction always gave deviations and excursions in a definite direction which cannot, however, be said to be positive in relation to the resting current on account of the inconstancy of the latter, which is due, no doubt, to the irregular construction of the organ. The preparation is, moreover, very perishable, and very soon gives no effect at all, or only (polarisation ?) effects, the direction of which varies with that of the exciting current.

The *lens* is much more easy to work with. From it one obtains, according to the position of the electrodes, well-marked though weak resting currents in a constant and definite direction. In response to excitation, effects in one direction (the positive) occur whatever the direction of the exciting current. They are frequently preceded by negative initial jerks when the exciting current is in the same direction, just as is the case in the whole eye. Although the "blaze currents" are in this case much stronger than they are in the ciliary body, those of the two together are not nearly sufficient to account for the currents in the whole eyeball. The only remaining part of the eye in which to seek for the principal seat of origin of those large differences of potential, which occur in the response of the whole eye, was now *per exclusionem* the *cornea*, and, according to expectation, this was found by experiment to give strong electromotive effects. The preparation was made by cutting into the eyeball at the edge of the cornea with scissors, and then cutting right round the limbus. The

* Waller, "On the Retinal Currents of the Frog's Eye, excited by Light and excited Electrically," 'Phil. Trans.,' B, vol. 193, p. 123.

† "On the 'Blaze Currents' of the Frog's Eyeball," 'Phil. Trans.,' B, vol. 194, p. 183.

inner surface of the removed cornea was placed on a little projection of the kaolin of the one electrode, the outer surface was connected by a thick piece of wick with the other. In response to every stimulation, large "blaze currents" occurred, which in all respects resembled those of the whole eyeball, even in their intensity, so that one would not have known that the experiment was not being made with the whole eye unless one had seen the preparation. The resting current was from the inner to the outer surface; each induction shock, in whichever direction, produced an effect in the same direction as the resting current. When the excitation was also in the same direction as the resting current, this (outgoing, Transl.) response was preceded by a well-marked initial effect in the opposite direction.

According to these observations, the principal place in which the "blaze currents" of the eyeball originate appears to be the cornea, while the ciliary ring and lens contribute thereto. The retina plays quite a subsidiary part in their production. The results of these experiments on the cornea give support to the analogies between skin and cornea in their behaviour to excitation, to which Waller, by comparing the eyeball and skin currents, has already drawn attention, although it must not be forgotten that, owing to the difficulty in preparing it, the cornea is a much damaged tissue.

The fact that the cornea, an epithelium which is free from mucous cells, possesses strong electromotive properties, has a distinct bearing on one question which has been sometimes discussed, namely, that as to whether it is the mucous cells or the ordinary epithelial cells that are the cause of the occurrence of differences of potential in skin, tongue, &c.

There is another point of interest in connection with these experiments which may be here mentioned, which is, that the "blaze currents," after reaching their maximum, seldom diminish at a constant rate. The diminution frequently takes place in a series of steps, *i.e.*, the current, after beginning to diminish at a regular rate, suddenly ceases to diminish for a few seconds or is even slightly augmented, thus causing a projection on the curve; it then diminishes again at its previous rate, being interrupted at intervals by fresh augmentations. This phenomenon also requires further study. In order not to increase the length of this communication, the curves obtained and the numbers from which they were derived will not be introduced.

It is the retina especially from which one might have expected to get large electromotive effects. The fact that the response to excitation observed in it was so small (and the little there was may not even have been entirely due to the retina, since the optic nerve and the sclerotic remained attached) is enough to suggest the question whether "blaze currents" may really be taken as a sign of the persistence of life,

their absence as a sign of its cessation. For the solution of this question, a few experiments were undertaken with other organs of the frog, namely, liver, kidney, and ovary of freshly-killed animals. With such specifically-surviving organs as liver and kidney one would have especially expected to find the currents which are supposed to be a sign of life.

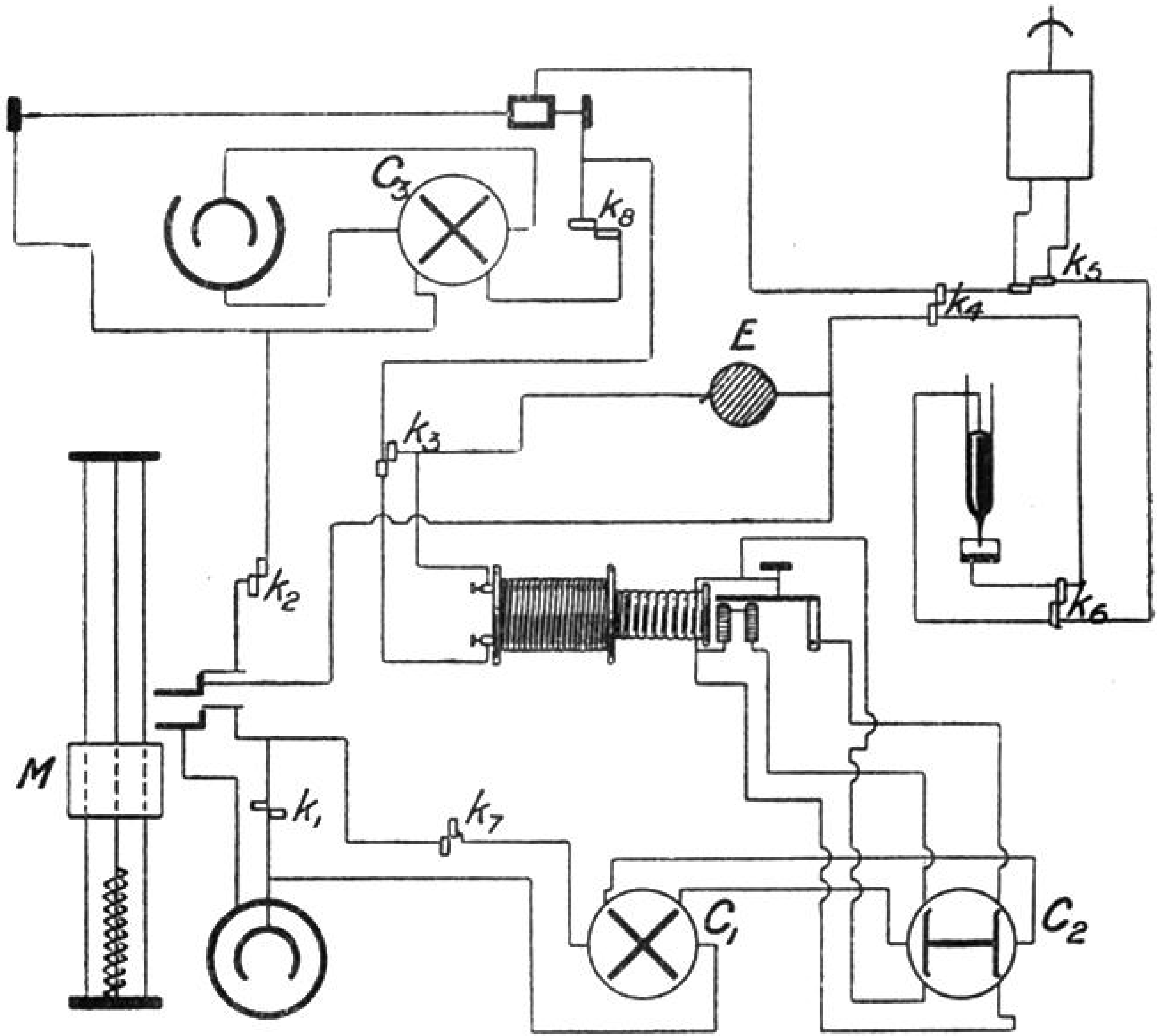
Experiments on Liver, Ovary and Kidney.

Only one out of all the experiments made gave a result which could in any way be compared with that obtained from the eye. The other preparations all gave electromotive effects which were often very considerable, but which cannot be otherwise regarded than as polarisation effects, since they varied with the direction of the exciting current and were always opposed to it. The one experiment which formed the exception can hardly be said to agree with the observations on the eye, since, although the excursions were certainly always in one direction, they varied enormously in extent, according to the direction of the exciting current, the proportion being sometimes as much as 8 to 1. Faradisation of the organs produced no result at all when the coil was so arranged that the make and break shocks were of equal intensity.

It seems to me no longer possible, after these observations, to regard the appearance of "blaze currents" as a specific property of living tissue. It is much more probable that they are to be considered as special manifestations of certain epithelial tissues.

Neither can the presence of exclusively polarisation effects be taken as the sign of the death of a tissue, since these may occur alone in a very pronounced manner in living organs, and in a few organs may even represent the regular and typical effect to stimulation.

In conclusion, it is my pleasant duty to thank Professor Gotch, in whose laboratory these experiments have been carried out, for the facilities afforded me.



C3
k8
k5
k4
E
k3
k2
k6
M
k1
k7
C1
C2